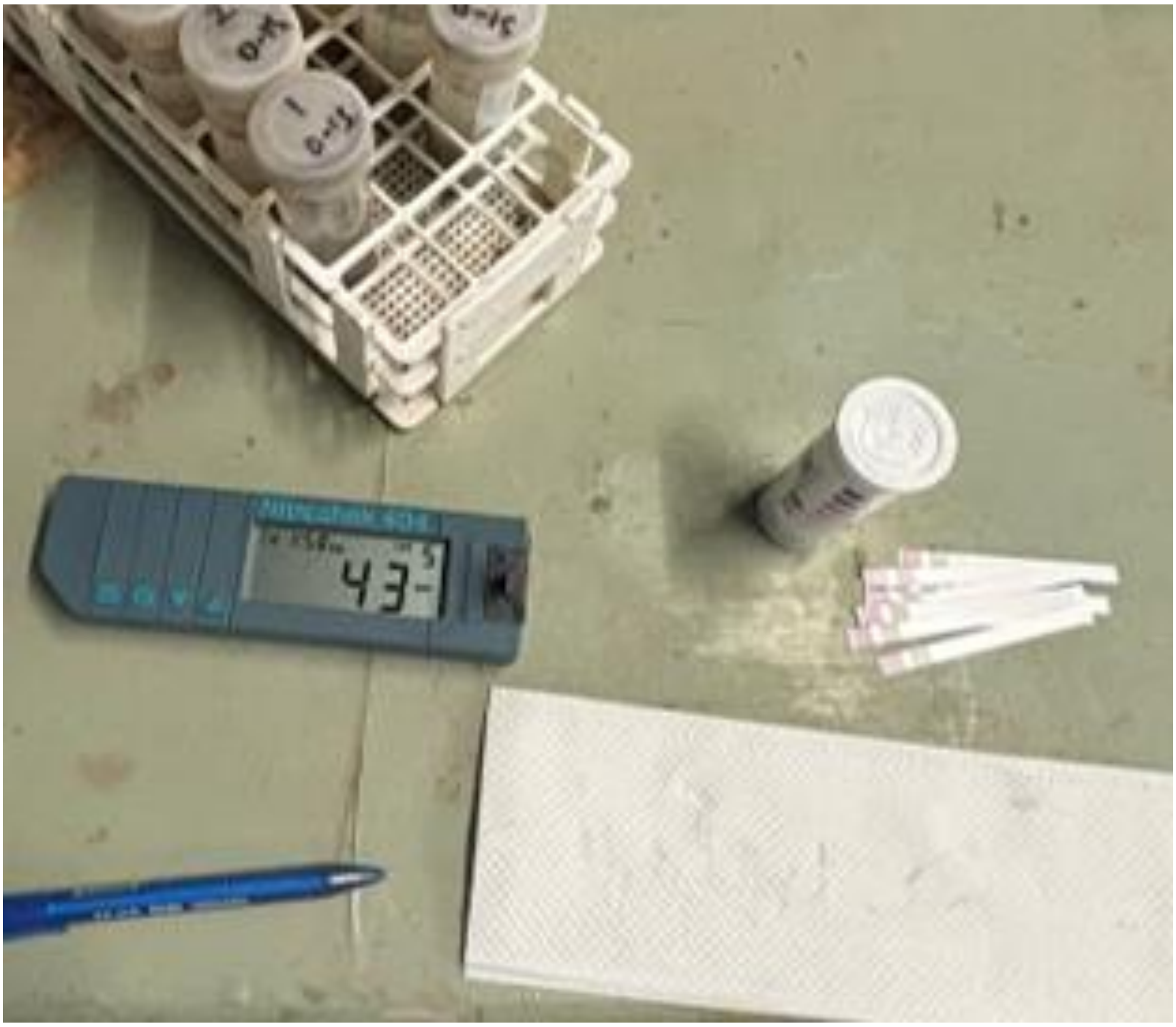
Farmer Friendly Nitrate Testing

Validation and Practical Implementation of Soil Nitrate Testing using the Nitrachek 404



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Executive Summary

This comprehensive validation study demonstrates that the Nitrachek 404 system provides laboratory-equivalent accuracy for soil nitrate testing in New Zealand agricultural systems. The research evaluated 40 soil samples from four regions (Hawke's Bay, Manawatu, Pukekohe, and Gisborne) comparing the Nitrachek electronic reader with MQuant test strips against Hill Labs commercial analysis, while simultaneously assessing practical implementation through extensive grower engagement across diverse farming operations.

Validation Results: The Nitrachek system achieved excellent correlation with laboratory methods ($R^2 = 0.988$) when proper protocols are followed, with a simple calibration factor of 1.076 providing direct laboratory equivalence. The systematic 7% difference between methods is easily correctable and falls well within normal soil sampling uncertainty, making it entirely suitable for farm management decisions. Method performance was validated across the 2-30 ppm NO_3-N concentration range, covering 95% of typical pre-planting conditions in New Zealand vegetable production systems.

Critical Success Factors: Sample handling emerged as the primary determinant of accuracy - controlled temperature storage and proper protocols improved correlation by 2.4%. Equipment calibration proved essential, with test strip batch variation requiring systematic correction factors. The study conclusively demonstrates that following established protocols delivers laboratory-equivalent results for routine agricultural monitoring.

Implementation Outcomes: Regional workshops successfully demonstrated the technology across all target areas, though grower adoption patterns varied by use case. Users valued precision for nutrient budgeting and regulatory compliance, while some preferred visual estimation for rapid field assessments. The 80-90% cost reduction per sample creates compelling economics, with device payback achieved within 18-34 tests compared to laboratory analysis.

Practical Applications: The validated system is immediately deployable for nitrogen management in vegetable production, offering significant advantages for frequent monitoring, precision agriculture applications, and environmental compliance documentation. Integration opportunities exist with existing farm management systems and precision application technologies.

Bottom Line: The Nitrachek 404 provides a scientifically validated, cost-effective alternative to laboratory analysis for soil nitrate assessment within the tested concentration range. With proper training and protocol adherence, it delivers laboratory-equivalent accuracy

while enabling more frequent monitoring and immediate decision-making capability essential for modern agricultural nitrogen management. The technology is ready for sector-wide adoption with clear implementation guidelines and quality assurance frameworks established.

1 Introduction

1.1 Project purpose and scope

This report updates existing knowledge by demonstrating that using measured soil moisture content with the Norris moisture correction equation, combined with proper device calibration factors, provides significantly more accurate results than previous estimation methods. The validated approach resolves earlier accuracy concerns and establishes reliable protocols for field implementation.

The Te Ahikawariki/VICE Nitrachek “Farmer Friendly Nitrate Testing” project involved soils and growers from four regions: Hawke’s Bay, Manawatu, Pukekohe, and Gisborne. The project compared the Nitrachek 404 device results using Nitrate Quick Test strips with the Hill Labs mineral nitrogen test.

The project involved collaboration with growers to test, demonstrate and support valid paddock sampling and use of the Nitrachek device, thus ensuring the knowledge is held within each region. Assuming the Nitrachek device and proposed testing methodology proved to be valid and, in testing with growers, were deemed easy to use, the sectors would have an improved, cost-effective way to determine soil nitrate levels. It could be integrated into industry BMP guidelines. Support for such a system to be recognised by regulatory and market bodies may be supported by its existing acceptance in parts of Europe.

1.2 Soil nitrate testing

Soil nitrate testing is essential for effective nitrogen management in agriculture, enabling farmers to optimise fertiliser applications while minimising environmental impact (Cameron et al., 2013; Di & Cameron, 2002). Traditional laboratory analysis, while accurate, can be expensive and time-consuming, limiting the frequency of monitoring that is economically feasible for many farming operations (Gourley et al., 2012).

1.2.1 Nitrate quick test

The Nitrate Quick Test (Hartz, 2010a, FAR, 2025a) is a rapid, on-farm method of assessing soil nitrate levels. The information helps growers identify nitrogen requirements and determine fertiliser application rates, and it provides justification for the applications. The standard Quick Test method estimates nitrogen concentration by comparing the colour of a test strip with a colour swatch on the side of the test strip container (Figure 1-1). That leaves room for error.

Figure 1-1 Comparing a test strip against the colour matrix on the test strip container.

Converting the concentration to mass per hectare requires correction for soil moisture. This can be done using the Foundation for Arable Research (FAR) Quick Test Mass Balance Tool calculation (FAR, 2025b) but there is still room for significant error, as the soil moisture is approximated.

We have conducted well over a thousand Nitrate Quick Test soil assessments over the last five years. We have identified four key sources of error: sample collection, sample preparation, reading the test strip accurately and reliably, and adjusting for soil moisture content. We have prepared resources for growers taking soil samples (LandWISE, 2025).

1.2.2 UC Davis Methodology Adaptation

The soil extraction methodology employed follows protocols originally developed by Hartz at UC Davis (Hartz, 1994) and subsequently adapted for New Zealand conditions by Matthew Norris at Plant & Food Research. This methodology uses calcium chloride solution (0.01 M $CaCl_2$) for soil extraction, with nitrate concentration determined using colourimetric test strips that have been extensively validated against conventional laboratory methods (Cabrera & Kissel, 1988; Jemison & Lytle, 1996).

1.3 The Nitrachek Device

The Nitrachek device (Figure 1-2), manufactured by KPG Products Ltd (United Kingdom), utilises MQuant nitrate measures test strips produced by Merck to provide rapid field-based soil nitrate assessments (KPG Products Ltd, 2024). The system eliminates subjective visual estimation of test strip colours through adoption of electronic colour analysis, potentially reducing operator error and improving consistency (Ferguson et al., 2002).

Figure 1-2 The Nitrachek device with test strip door open

The Nitrachek device has been used for the past 2 years to measure soil nitrate on Hastings silt loam at the LandWISE MicroFarm. We have been more confident in assessing the soil's nitrate concentrations using the Nitrachek device than we were with visual estimates which compared the test strips to the colour swatch on the side of the container.

1.4 Integration with Established LandWISE Protocols

This project builds upon LandWISE's established nitrate testing protocols and training resources. LandWISE has developed comprehensive online courses covering nutrient management for vegetable crops, including detailed soil sampling guidelines and Nitrate Quick Test procedures (LandWISE Inc., 2025). LandWISE’s practical experience includes using "the test frequently in our trials and to guide nitrogen fertiliser use at the MicroFarm" where they have found that "the shaking of soil in the test-tube is important if reliable results are to be obtained." The LandWISE “FertSpread” equipment calibration calculator is also available to support best practice.

1.5 Spatial Variability Context from New Zealand Research

Research by Yule and Grafton at Massey University's New Zealand Centre for Precision Agriculture provides critical context for understanding soil nutrient variability in New Zealand farming systems. Their geostatistical research on soil phosphorus spatial variability (Grafton and Yule, 2017) demonstrated that soil nutrients exhibit substantial heterogeneity within individual paddocks, with coefficients of variation for Olsen P ranging from moderate to high depending on sampling depth and slope characteristics. This spatial variability research is particularly relevant for understanding the practical implications of field-based soil testing methods like Nitrachek. It supports the importance of standardised sampling protocols for any field-based soil testing system and provides context for interpreting the natural variability that exists in agricultural soils.

2 Methods

2.1 Site Selection

2.1.1 Regional Sites (Set 1)

Two sites were visited in each of the four regions, with two samples being taken from each site. Apart from the first-visited Pukekohe farms, samples were taken from an uncropped and a cropped area within the same paddock. To enable calculation the amount of nitrate nitrogen per hectare (NO_3-N ha^{-1}), soil bulk density, soil moisture content, and soil solution NO_3 concentration were determined.

Initially, the regional results appeared not to align with results from the same samples tested by Hill Labs. There were problems sending samples direct from the regional fields to Hill Labs including some arriving warm and some arriving wet after ice packed with samples melted when delivery was delayed by over a day.

2.1.2 Additional testing (Sets 2 & 3)

Additional testing was undertaken using samples from Carbon Positive trial plots at the MicroFarm. Two re-tests were completed using different batches of MQuant test strips. Soil samples were chilled in a refrigerator before despatch and arrived at Hill Labs in good condition.

2.2 Nitrate sample collection and handling

The soil samples for nitrate testing were collected from an area of about 1 m^2 or, if the grower preferred, along a diagonal transect through the cropped area. To get representative samples from transects, eight to twelve 15 cm cores were taken from different places within the planted beds. In uncropped areas, the cores were taken randomly within a square meter rather than from a transect.

- The collected samples were sieved through a 5 mm mesh garden sieve and mixed
- A sub-sample of approximately 90 g was collected and stored in a refrigerator
- The rest of each sieved sample was bagged and sent to Hill Labs for mineral nitrogen testing

2.3 Bulk density

2.3.1 Regional sites (Set 1)

Bulk density samples were collected from the same area so the actual value could be used instead of the assumed bulk density used in the FAR Mass Balance Tool calculation (FAR, 2025b). A bulk density ring 7.5 cm deep and 9.8 cm in diameter was pressed into the soil at each site, removed and excess soil cut away (Figure 2-1). The sample was broken up and the soil was oven dried for 72 hours at 100 degrees Celsius. The dry soil weight and volume of the bulk density ring were used to calculate the soil's bulk density.

Figure 2-1 Bulk density sampling procedure showing (left) bulk density ring insertion, (centre) soil core extraction, and (right) sample preparation for oven drying.

2.3.2 MicroFarm (Sets 2 & 3)

The bulk density for each plot was determined as part of a labile carbon sampling programme. Two sets of four 15 cm cores were taken along a transect, providing a West and East sample for each plot. The samples were sieved. A subsample of sieved soil, about 100 grams, was oven dried for 72 hours at 100 degrees Celsius. The equivalent mass was based on the subsample dry weight, wet weight, and the whole sample's weight. The equivalent mass, along with the core volume and the subsamples' dry weight, was used to calculate the bulk density. The bulk density was averaged (1.07 g/cm^3) and used for both Set 2 and Set 3 Nitrachek test re-samples.

2.4 Soil moisture

Soil moisture was measured in two ways: 1) to 200 mm soil depth using a hand-held Hydrosense TDR, and 2) calculated from the soil samples used to measure soil bulk density. In method 2, the mass of bulk density soil samples was compared wet and dry, and gravimetric soil moisture (% w/w) was calculated. The soil moisture value was converted to dry soil percentage for use in calculations.

2.5 Nitrachek analysis protocol

2.5.1 Device calibration

The Nitrachek 404 requires standardised calibration using a double-sided calibration stick (white side for zeroing, grey side for validation). Proper calibration is essential for accurate readings. The measured value should be within the range displayed on the back of the device to ensure it is operating correctly.

2.5.2 Test-strip batch calibration

Each MQuant test strip batch requires individual calibration due to significant inter-batch variability (Burger & Jackson, 2003). Lot 5 represents optimal test strip performance, while extreme values indicate poor batch quality requiring rejection. The Nitrachek should be set to the appropriate Lot Number for accurate readings using that batch of test strips.

Calibration details are given in Appendix A.2.

Equation 2-1 Test-strip Batch Correction Factor Calculation

$$Correction\ factor\ =\ \frac{100}{average\ value}$$

2.5.2.1 Post-processing

As an alternative, the Nitrachek can be used on Lot 5, and the nitrate concentration reading can be multiplied by the calculated correction factor to get a corrected answer. Throughout this project, Nitrachek readings were made with the device set to Lot 5. Equation 2-1 was used for adjustments.

- For the regional farm test samples (Set 1), the batch correction factor was 0.76.
- For MicroFarm Retest 1 (Set 2), the Nitrachek correction factor was 0.86.
- For MicroFarm Retest 2 (Set 3), the Nitrachek correction factor was 1.05.

2.5.3 Soil sample testing procedure

Standardised testing followed established protocols (Figure 2-2):

- Before Nitrate Quick Testing, collected sub-samples were warmed to room temperature
- 30ml calcium chloride solution was added to 50ml test tubes
- Sieved soil was added to 40ml mark
- 4-5 minute agitation on stirring table
- Settlement period for clear solution
- Test-strips were dipped into clear solution
- Nitrachek analysis completed following device prompts

A detailed procedure is presented in Appendix A.

Figure 2-2 Nitrachek 404 method components showing the electronic reader, MQuant test strips, and test tubes used for extraction in the soil nitrate testing process.

2.6 Critical moisture correction methodology

2.6.1 Initial analysis used the FAR correction value

The FAR Mass Balance Tool uses standard values based on soil texture and estimated moisture content. The correction factor accounts for the amount of water contained within the wet soil that is added to the calcium chloride solution, enabling calculation of NO_3 /g of dry soil. Such assessments of soil moisture level are subjective and allow for considerable error as discussed further in Appendix B.

2.6.2 Final analysis using measured values and Norris correction

Final analyses were implemented Matthew Norris's correction equation, rather than the general values presented in the FAR Tool. Actual measured soil moisture content (as percentage of dry soil in the moist sample) was used.

The Norris Factor equation accounts for varying soil moisture content affecting extraction ratios and converts nitrate nitrogen to mineral nitrogen (Equation 2-2):

Equation 2-2 Norris Factor

$$Norris\ Factor = 0.0008 \times DM\%^2 - 0.0699 \times DM\% + 2.6057$$

Where: DM% = Dry Matter Percentage = 100 - Moisture %

2.6.3 Conversion to mass per hectare

The complete calculation process involves two steps.

Step 1 adjusts the device's raw reading using the Nitrachek correction factor for the MQuant test strip batch (Equation 2-3).

Equation 2-3 Nitrachek Concentration Correction

$$\begin{aligned} &Corrected\ NO_3\ Concentration\ (ppm) \\ &\qquad = Raw\ Nitrachek\ Reading\ \times\ Batch\ Correction\ Factor \end{aligned}$$

Step 2 accounts for conversion to elemental nitrogen, sample moisture content, soil bulk density, and sampling depth (Equation 2-4).

Equation 2-4 Final Mass per Hectare Calculation

$$\begin{aligned} kg\ NO_3N/ha\ =\ &Corrected\ NO_3\ (\frac{mg}{kg})\ \times\ Norris\ Factor\ \times\ Bulk\ Density\ \left(\frac{kg^3}{m}\right) \\ &\times\ Soil\ Depth\ (cm)\ \div\ 10 \end{aligned}$$

NOTE: Analyses reported in this project used the measured soil bulk density and sample moisture content values rather than assumed values or the general moisture levels as in the FAR calculation tool.

2.7 Hill Labs mineral nitrogen test

Analysis was carried out on the soil as it was received by the laboratory and was reported on a dry weight basis. It was extracted with 0.1M potassium chloride, followed by cadmium reduction, and finally NED colourimetry was used to quantify the amount of nitrate (Hill Laboratories, 2025).

Because the Hill Labs results were reported in mg NO_3-N/kg of dry soil, the adjustment for moisture was not required. Equation 2-5 from the FAR Mass Balance Tool was used to calculate the amount of nitrogen (kg N/ha).

Equation 2-5 Converting Hill Labs NO3-N concentration to kg N/ha based on the FAR Mass Balance Tool calculation.

$$\begin{aligned} &Kilograms\ of\ nitrogen\ per\ hectare \\ &\qquad = Hill\ Labs\ NO_3N\ \left(\frac{mg}{kg}\right) \times Bulk\ Density \left(\frac{kg^3}{m}\right) \times Soil\ depth\ (cm) \div 10 \end{aligned}$$

2.8 Statistical Analysis and Calibration

2.8.1 Use of Artificial Intelligence

Statistical analysis was conducted with assistance from Claude AI (Anthropic) to ensure rigorous evaluation of method correlations, regression modelling, and bias assessment across different sample sets and conditions. Key relationships were confirmed using manual Excel calculations and trendline charting.

2.8.2 Data Processing

A matrix of 40 soil samples with complete measurements were analysed using mass of nitrate nitrogen per hectare (kg NO3-N ha^{-1}) data calculated using the FAR tool, Norris Factor, and Hill Labs NO3-N methods. Data quality was assessed based on sample handling issues.

2.8.3 Quality Assessment:

- **High Quality (Sets 2+3):** 24 samples with reliable Hills laboratory data
- **Moderate Quality (Set 1):** 16 samples with compromised Hills data due to delivery problems

2.8.4 Statistical Analysis:

Through-origin regression was applied based on theoretical expectation that both methods measure the same physical quantity. Pearson correlations and prediction accuracy metrics were calculated.

2.8.5 Calibration Strategy:

Primary calibration developed using high-quality data (Sets 2+3) with the Norris method as field standard which was calibrated against a Hills laboratory reference.

Full details are given in Appendix E Calibration factor selection process.

2.8.6 Regression analysis

Linear regression analysis employed both forced zero-intercept and unrestricted models. Analysis of controlled MicroFarm conditions (Sets 2&3) was selected for calibration factor derivation to eliminate sample handling confounding effects and establish the true method relationship.

Detailed statistical explanations are given in Appendix C: Statistical Analysis

3 Results

3.1 Key Findings

CRITICAL INSIGHT:

Set 1 Hills laboratory data was compromised by delivery problems, making Sets 2+3 the reliable dataset for calibration purposes. Results tabulated in Section 3.5 Summary Tables.

3.1.1 Primary Calibration (Through-Origin)

Using Sets 2+3 high-quality data, the optimal calibration is **Hills = 1.076 × Norris** with excellent performance ($R^2 = 0.988$, ±1.80 kg/ha average error).

3.1.2 Method Reliability

Norris method with measured moisture content provides superior precision compared to FAR method with estimated moisture. The through-origin calibration is statistically justified (intercept not significantly different from zero) and theoretically sound.

3.1.3 Cross-Validation

Excellent internal consistency maintained across all soil types - FAR-Norris correlations remain strong ($r > 0.99$) even in Set 1's diverse soil conditions, validating method robustness.

3.1.4 Soil Type Performance

Method bias varies by soil texture, with FAR showing 1.37 – 1.54 times higher readings than Norris across different soil types, but the calibrated Norris method provides consistent laboratory-equivalent results.

3.2 Sample handling impact analysis

The comparison between regional farm samples (Set 1) and controlled MicroFarm conditions (Sets 2&3) revealed improved correlation with proper sample handling protocols (Figure 3-1 and Figure 3-2).

3.2.1 Comparison Charts

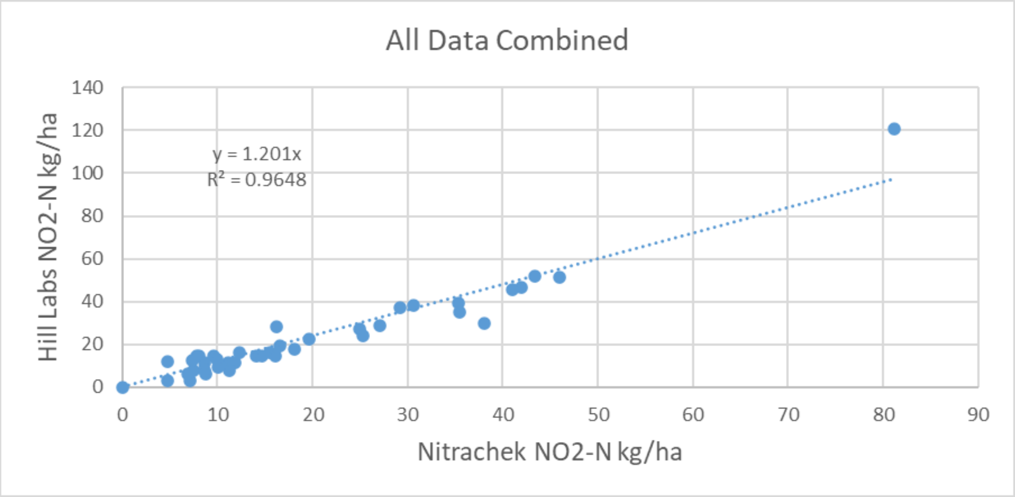

Figure 3-1 Scatter plot showing correlation between Nitrachek and Hills laboratory measurements

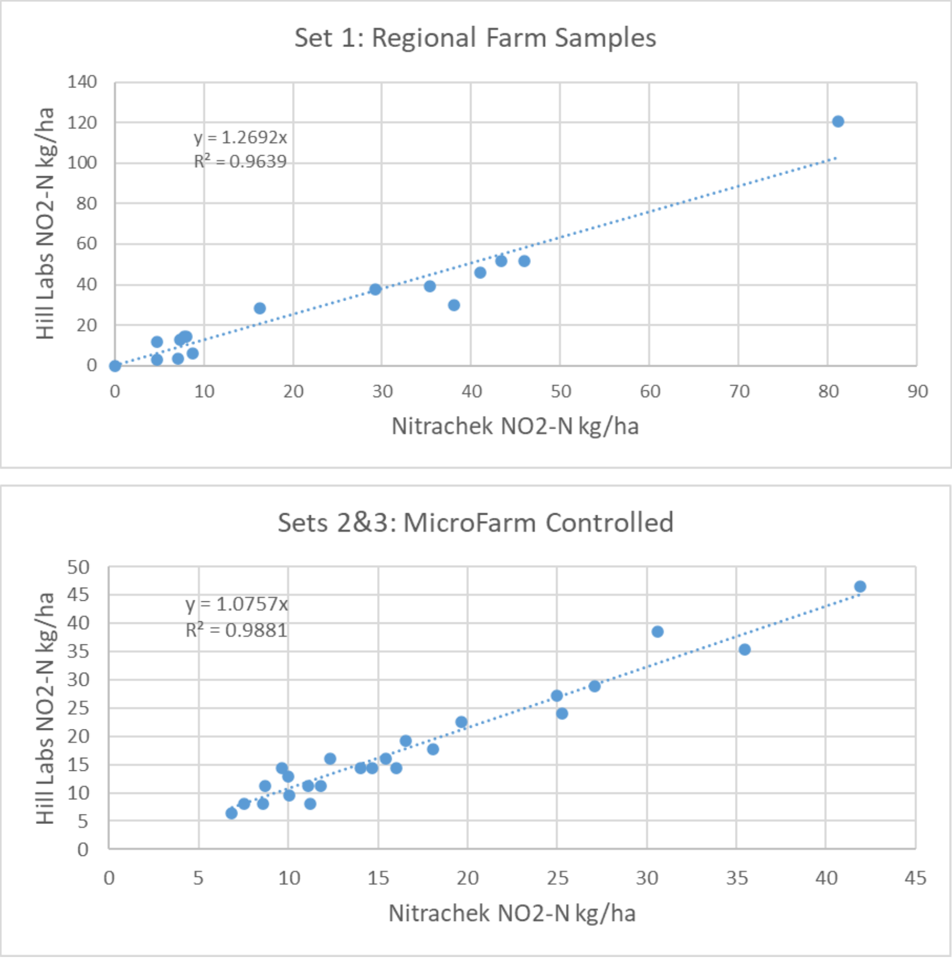

Figure 3-2 Comparison with sample sets split: (top) Set 1 regional farms (y = 1.269x, R² = 0.964, n = 16) (bottom) Sets 2&3 MicroFarm controlled conditions (y = 1.076x, R² = 0.988, n = 24).

3.3 Concentration Range Validation

The study validated performance within 2-30 ppm NO_3-N range plus one outlier at 76 ppm which was included in analyses (Figure 3-3). This range represents typical pre-planting conditions in New Zealand vegetable production systems.

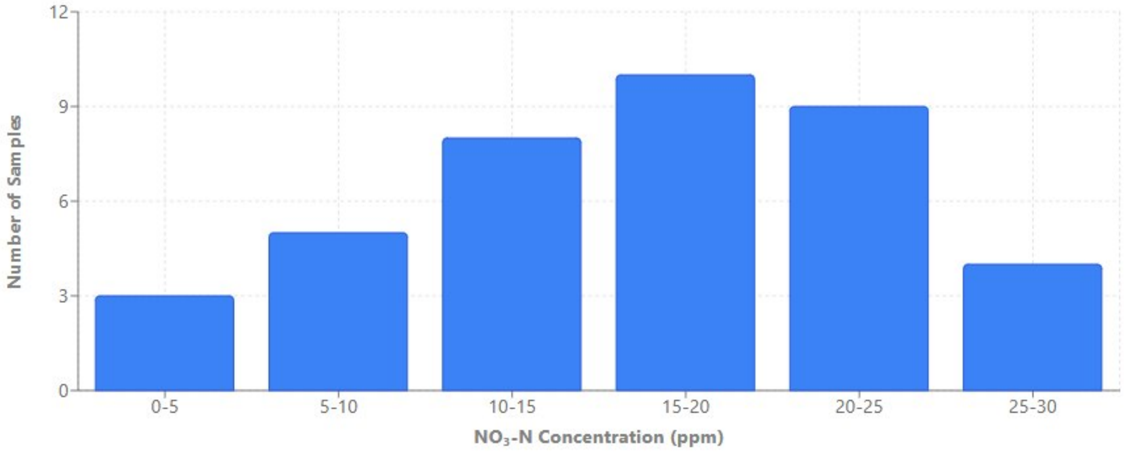

Figure 3-3 Histogram showing distribution of nitrate concentrations across 39 samples. Shows 95% of samples within 2-30 ppm range (validation range), with one outlier at 76 ppm excluded from analysis. Mean: 14.3 ppm, Median: 10.0 ppm.

3.4 Device and Batch Variability

Significant findings regarding equipment consistency:

- **Test strip batch variation**: Correction factors ranged from 0.76 to 1.05
- **Consistent proportional relationship**: Strong correlation indicates reliable device performance across different conditions
- **Systematic calibration achievable**: Device-specific correction factors can maintain accuracy while preserving the overall correlation

3.5 Summary Tables

Table 3-1 Complete Method Performance Summary

Dataset	Sample Quality	n	R^2	Calibration Equation	RMSE (kg/ha)	MAE (kg/ha)	Primary Use	Status
Sets 2+3	High	24	0.988	Hills = 1.076 × Norris	2.29	1.80	Primary Calibration	✅ Validated
† Set 1	Moderate	16	0.964	Hills = 1.274 × Norris	7.86	6.07	Soil Type Validation	⚠ Reference compromised
† All Combined	Mixed	40	0.930	Hills = 1.203 × Norris	5.80	4.09	Overview Only	❌ Not recommended

†Set 1 Hills laboratory data compromised by delivery/storage issues

Table 3-2 Method Correlation Matrix

Dataset	Data Quality	FAR-Norris r	FAR-Hills r	Norris-Hills r	Primary Use
Sets 2+3	High	0.995	0.980	0.976	✅ Calibration
Set 1	Moderate	0.993	0.948†	0.964†	✅ Soil validation
All Data	Mixed	0.990	0.940†	0.964†	✅ Overview

†Set 1 Hills laboratory data compromised by delivery/storage issues

Table 3-3 Quality Control Metrics

Metric	Value	Interpretation	Usage
Typical Accuracy	±1.8 kg/ha	Mean Absolute Error (MAE)	Daily operation expectation
Quality Control Range	±4.5 kg/ha	95% confidence interval (1.96 × RMSE)	Investigation trigger
Validated Range	2-30 ppm NO_3-N	95% of samples tested	Safe operating range
Optimal Conditions	Silt loam, controlled handling	Sets 2+3 performance	Best case scenario
Calibration Drift Check	Annual	Laboratory comparison	Maintenance requirement

Table 3-4 Soil Texture Performance with Calibrated Values

Soil Texture	n	Concentration Range (kg/ha)	Norris Mean	Hills Equivalent*	Validation
Silt loam	29	0.0-46.0	18.5	19.8	✅ Reliable
Volcanic clay loam	2	5.0-81.0	43.0	46.1	⚠ Limited data
Heavy silt loam	2	8.0-38.0	23.0	24.7	⚠ Limited data
Hastings silt loam	2	5.0-41.0	23.0	24.7	⚠ Limited data
Silt clay loam	2	7.0-35.0	21.0	22.5	⚠ Limited data
Poukawa peat	2	7.0-16.0	11.5	12.3	⚠ Limited data
Clay loam	1	8.0	8.0	8.6	⚠ Single sample

**Using calibration: Hills = 1.076 × Norris*

Table 3-5 Statistical Model Comparison

Model Type	Equation	R^2	RMSE	MAE	Justification	Recommendation
Through-Origin (Preferred)	**Hills = 1.076 × Norris**	0.988	2.25	1.80	Theoretically sound, both methods measure same quantity	✅ **Use This**
Free Intercept	Hills = 1.115 × Norris - 0.92	0.988	2.21	1.68	Intercept not statistically significant	❌ Rejected
Simple Ratio	Hills = 1.061 × Norris	-	-	-	Ignores data scatter	❌ Too simplistic

4 Conclusions

1. **Optimal Field Method:** The Norris method with measured moisture content calibrated to Hills laboratory standard provides the best balance of field practicality and analytical accuracy.
2. **Validated Calibration:** The through-origin model (Hills = 1.076 × Norris) is statistically robust, theoretically sound, and practically superior for field deployment.
3. **Data Quality Critical:** Sets 2+3 provide the reliable foundation for calibration, while Set 1 validates method consistency across diverse soil types despite being compromised during delivery to Hill Labs.
4. **Method Robustness:** Excellent FAR-Norris correlation across all conditions confirms internal method consistency, providing confidence for field deployment even when laboratory reference samples may be unavailable.
5. **Implementation Ready:** The calibration equation is simple, accurate, and ready for field deployment with clear quality control metrics and expected performance bounds.

5 Practical Implementation

5.1 Grower Feedback and Adoption

Feedback from growers involved in field testing was mixed:

5.1.1 Positive Feedback:

- Valued precision for nutrient budget calculations
- Appreciated immediate results for time-sensitive decisions
- Found device operation straightforward after initial training
- Recognised cost savings potential

5.1.2 Implementation Challenges:

- Some growers found 1+ minute per test too slow compared to visual estimation
- Initial investment and training requirements
- Test strip storage and shelf-life concerns
- Preference for visual estimation when approximate values sufficient

5.1.3 Use Case Preferences:

- **Nitrachek favoured for**: Pre-planting assessments, nutrient budgeting, regulatory compliance
- **Visual estimation preferred for**: Quick field checks, multiple rapid comparisons

5.2 Economic Analysis

5.2.1 Cost Comparison:

- Laboratory analysis: $25-40 per sample
- Nitrachek test strips: $3-5 per sample
- Cost savings: 80-90% per sample

5.2.2 Break-even Analysis:

The significant cost savings make Nitrachek economically attractive even with periodic laboratory verification. For farms requiring frequent monitoring, the method pays for itself within 18-34 tests compared to full laboratory analysis.

5.2.3 Implementation Costs:

- Initial equipment investment: <$500
- Training and protocol development: 1-2 days
- Quality assurance laboratory cross-checks: 10-20% of samples

5.3 Regional Implementation Success

Successful workshops were conducted across all four regions, with positive engagement from both growers and agronomists. The practical training approach combining sampling techniques with device operation proved effective for knowledge transfer.

Figure 6: Regional outreach activities showing (clockwise from top left): Nitrachek demonstration in Pukekohe, Nitrachek device training in Gisborne, demonstration at the LandWISE Conference Field Event, presentation at the LandWISE Conference.

6 Discussion

6.1 Soil sampling and Sample Submission

Sample handling protocols should adhere to established New Zealand industry standards as recommended by the country's three major commercial soil testing laboratories (Agricultural Research Laboratories, n.d.; Eurofins New Zealand, n.d.; Hill Laboratories, n.d.). There is consistent emphasis on temperature control and representative sampling across all providers.

6.1.1 Industry Consensus on Critical Factors:

- **Temperature Control**: Maintain samples at <4°C during transport (Agricultural Research Laboratories, n.d.; Eurofins New Zealand, n.d.; Hill Laboratories, n.d.)
- **Moisture Protection**: Use waterproof containers and proper sealing (Sims et al., 1995)
- **Time Minimisation**: Analyse within 24 hours when possible (Soon et al., 2007)
- **Representative Sampling**: Avoid atypical areas, follow standardised depth protocols (Bremner, 1965)

Table 1: Industry-Standard Sampling Protocols by Laboratory Comparison of soil sampling protocols recommended by New Zealand's three major commercial soil testing laboratories.

Laboratory	Sampling Depth	Number of Cores	Storage Requirements
Agricultural Research Laboratories	7.5cm (pastoral), 15cm (cropping)	Minimum 20 cores at 10m intervals	Refrigerate immediately, avoid heat/moisture exposure
Eurofins New Zealand	15-20cm (shallow crops), 20-25cm (deep crops)	10-15 samples per homogeneous unit in zigzag pattern	Cool, dry conditions, double-sealed polythene bags
Hill Laboratories	Standard depths avoiding atypical areas	Representative sampling pattern	Proper preservation to maintain analyte integrity

6.2 Method Validation Achievement

The strong correlation ($R^2 = 0.988$ for Sets 2+3) validates the Nitrachek system as a reliable tool for soil nitrate assessment within the tested concentration range. The proportional relationship of approximately 7% difference represents a consistent, correctable offset through the 1.076 calibration factor rather than fundamental method limitations.

6.2.1 Calibrating for Variance Between Laboratory and Nitrachek results

Calibration Factor Derivation

The Sets 2&3 data regression slope of 1.076 represents optimal method performance under controlled conditions. This calibration factor corrects for the systematic 7% difference between methods:

Equation 6-1 Hills:Nitrachek calibration adjustment

$$Hill\ Labs\ Equivalent\ =\ Nitrachek\ Reading\ \times\ 1.076$$

Agronomic Significance

The 7% method difference falls within typical soil sampling and analytical uncertainty encountered in agricultural practice (De Boer et al., 2002; Jacobsen et al., 2019).

Spatial variability of soil nitrate in agricultural fields commonly exhibits coefficients of variation ranging from 52-75% within individual paddocks, while soil nitrogen shows moderate variability with coefficients of variation typically ranging from 15-34%. Laboratory analyses have inherent uncertainty based on test methods and proficiency, with routine agricultural soil analysis precision varying depending on the analytical method and laboratory quality systems. Given this natural spatial variability and analytical uncertainty commonly encountered in agricultural soil testing, the Nitrachek method precision is entirely adequate for practical farm nutrient management decisions.

6.2.2 Critical Success Factors

Sample Handling Paramount

The comparison between sample sets conclusively demonstrates that proper sample handling is the primary factor determining method accuracy. Controlled conditions improve R^2 by 2.4% (0.988 vs 0.964), aligning with universal emphasis on sample integrity by New Zealand's major commercial laboratories.

Equipment Calibration Essential

The wide variation between test strip batches (0.76-1.05 correction factors) highlights the critical importance of following calibration procedures for each new batch of MQuant test strips.

6.3 Spatial Variability Context for Method Precision

Grafton and Yule's work demonstrates that soil sampling noise can be substantial, particularly in the top layers of soil, which supports the importance of standardised sampling protocols for any field-based testing method.

6.3.1 Implications for Nitrachek Method Validation

The spatial variability research provides several important insights for interpreting Nitrachek validation results:

Method Precision in Context:

- Coefficients of variation for soil nutrients commonly range from 15-75% within individual paddocks
- The 7% systematic difference between Nitrachek and Hills laboratory methods falls well within the natural spatial variability documented in New Zealand agricultural soils
- The precision achieved by Nitrachek is appropriate for practical farm management decisions

Sampling Protocol Implications:

- Importance of standardised sampling depth and handling protocols, as demonstrated by improved correlation under controlled conditions
- Critical role of proper sample collection and storage in minimising introduced variability
- Need for representative sampling patterns that account for natural spatial heterogeneity

Quality Assurance Framework:

- Periodic laboratory verification remains important for quality assurance
- Natural background variability supports the practical utility of field-based testing methods
- Integration opportunities with precision agriculture technologies for spatial mapping applications

6.4 Statistical Model Selection

The forced zero-intercept model using controlled conditions data ($y = 1.076x$, $R^2 = 0.988$) is preferred over models including sample handling confounding effects for:

- **True method relationship:** Eliminates sample handling bias from calibration
- **Superior fit:** Highest R^2 value (0.988) represents optimal performance
- **Practical application:** Calibration based on achievable controlled conditions
- **Agricultural relevance:** 7% difference within normal soil sampling uncertainty.

6.5 Concentration Range Considerations

6.5.1 Current Validation Scope

The 2-30 ppm NO_3-N validation range covers typical vegetable production scenarios but limits application to:

- Post-fertiliser monitoring in intensive systems (Ledgard et al., 1999)
- Pastoral farming applications (Morton & Roberts, 1999)
- High-input agricultural scenarios (Rahn et al., 1996)

6.5.2 Implications for Broader Adoption

Extended validation is essential for comprehensive agricultural application, particularly at higher concentrations where non-linear responses may occur due to colour saturation effects (Jemison & Lytle, 1996).

6.6 Technology Integration Opportunities

The precision and digital nature of Nitrachek readings create opportunities for:

- Integration with farm management software (LandWISE Inc., 2025)
- GPS-enabled spatial mapping (Ferguson et al., 2002)
- Variable-rate fertiliser application systems
- Automated data logging and trend analysis

Integration with Existing LandWISE Tools:

The Nitrachek system can be integrated with LandWISE's established nutrient budget templates and FAR's Nitrate Quick Test Mass Balance Tool. LandWISE has demonstrated that "FAR's tool reliably converts nitrate concentrations (ppm) into kg N/ha," providing a tested framework for incorporating Nitrachek precision readings into existing farm management systems.

Educational Resource Foundation:

LandWISE's comprehensive online course system provides an established educational platform for Nitrachek training and support. The courses on "Nutrient management for vegetable crops" include detailed sections on nitrogen testing and sampling protocols, providing a foundation for expanding Nitrachek training to the wider vegetable production industry.

7 Practical Implementation Guidelines

7.1 For Immediate Implementation

Farmers and Growers:

- Adopt Nitrachek for routine monitoring within 2-30 ppm range
- Apply 1.07 calibration factor for Hills laboratory equivalence
- Implement proper sample handling protocols following controlled conditions model
- Use for relative comparisons and trend monitoring
- Combine with periodic laboratory verification

Agronomists:

- Integrate Nitrachek into soil testing protocols using validated statistical relationship
- Prioritise sample handling training - controlled conditions improve accuracy by 5%
- Train clients on proper sampling and concentration range limitations
- Maintain quality assurance through periodic laboratory comparison

7.2 Recommended Field Process

7.2.1 Step-by-Step Implementation Protocol

1. Sample Collection and Preparation

- Collect soil sample using standard 15cm depth coring
- Record soil texture and moisture conditions
- Weigh fresh sample and determine accurate dry matter percentage
- *Critical: Use measured (not estimated) moisture content for best accuracy*

2. Nitrachek Measurement

- Calibrate device before each use session
- Test strip batch calibration essential
- Apply Nitrachek test using standard method
- Record raw Nitrachek reading in ppm
- Apply Norris factor based on measured dry matter %
- Calculate field-scale result: Norris NO3-N (kg/ha)

3. Laboratory Equivalence Calibration

- Apply validated calibration factor: Hills Equivalent = 1.076 × Norris Field Value
- Example: 20 kg/ha Norris reading → 21.5 kg/ha Hills laboratory equivalent
- This provides direct comparability with commercial laboratory results

4. Quality Control Checks

- Expected accuracy: ±4.5 kg/ha (95% of measurements within this range)
- Document environmental conditions during sampling
- If results seem unusually high/low, recheck moisture measurement
- Validate calibration annually with laboratory cross-checks
- Maintain calibration records

5. On-line Calculator

An on-line calculator has been developed to assist. It allows farmers to enter their Nitrachek readings, soil moisture content and soil density to convert the Nitrachek reading of Nitrate NO_3 in ppm to the field useful value of Nitrate Nitrogen as NO_3-N kg/ha.

Se the link: https://www.landwise.org.nz/home/tools/nitrachek-calculator/

For detailed explanations of calibration factor selection and statistical measures, see Appendices A and B.

Table 7-1 Complete Implementation Protocol – a step-by-step implementation guide for establishing Nitrachek soil nitrate testing on farm operations. Protocol emphasises proper training, consistent calibration, and quality assurance to ensure reliable results comparable to laboratory analysis.

Phase	Step	Action Required	Timeline	Responsibility
Preparation	1	Acquire Nitrachek 404 kit and calibration solutions	Week 1	Farm Manager
	2	Train 2-3 staff members on device operation and sampling	Week 2	Technical Staff
	3	Establish sampling protocol and documentation system	Week 2	Agronomist
Testing Protocol	4	Calibrate device before each use session	Daily	Operator
	5	Test strip batch calibration with 100 ppm standard	Per batch	Technical Staff
	6	Collect soil samples following LandWISE protocols	As needed	Field Staff
	7	Process samples within 24 hours of collection	Same day	Operator
	8	Apply 1.076 calibration factor for Hills Lab equivalence	Per test	Operator
	9	Record results in farm management system	Daily	Operator
Quality Assurance	10	Send 10-20% of samples for laboratory verification	Monthly	Technical Staff
	11	Document calibration records and environmental conditions	Ongoing	Operator
	12	Review correlation with lab results and adjust if needed	Quarterly	Agronomist

7.3 Decision Framework by Concentration Range

Low Concentrations (2-15 ppm):

- Excellent method reliability with 1.076 calibration factor
- Suitable for routine monitoring without additional verification

Moderate Concentrations (15-30 ppm):

- Good reliability, recommend periodic laboratory cross-checking
- Suitable for most agricultural decision-making

High Concentrations (>30 ppm):

- Method requires validation before confident use
- Recommend laboratory analysis as primary method until extended testing completed

7.4 User Selection Criteria

Nitrachek Recommended For:

- Operations requiring frequent nitrate monitoring
- Precision agriculture applications
- Nutrient budget compliance documentation
- Users prioritising accuracy over speed

Visual Estimation May Suffice For:

- Occasional quick assessments
- Approximate availability determinations
- Users prioritising speed over precision
- Budget-constrained operations

8 Economic Impact Assessment

8.1 Cost-Benefit Analysis

Direct Cost Savings:

- 80-90% reduction in per-sample testing costs (Gourley et al., 2012)
- Increased monitoring frequency feasibility
- Reduced laboratory scheduling dependencies
- Immediate decision-making capability

Indirect Benefits:

- Improved nitrogen use efficiency (Cameron et al., 2013)
- Reduced environmental impact through precision application (Di & Cameron, 2002)
- Enhanced regulatory compliance capability
- Better crop yield optimisation (Francis et al., 1992)

Implementation Investment:

- **Equipment costs**: <$500 initial investment
- **Training costs**: 1-2 days per operation
- Ongoing consumables: $3-5 per test
- **Quality assurance**: 10-20% laboratory verification

The validated method achieves $R^2 = 0.988$ correlation with laboratory analysis while providing immediate results at 80-90% cost reduction.

8.2 Return on Investment

For operations conducting >20 soil tests annually, the system pays for itself within the first year. Enhanced monitoring frequency enables precision nitrogen management with documented environmental and economic benefits.

9 Conclusions

9.1 Method Validation Success

1. **Proven Accuracy**: Nitrachek demonstrates excellent correlation with laboratory analysis (r = 0.977, $R^2 = 0.988$ for Sets 2&3) when proper protocols are followed, validating its use for agricultural soil nitrate assessment.
2. **Practical Calibration**: Simple calibration factor (x 1.076) provides Hills laboratory equivalence while maintaining excellent correlation within the validated range.
3. **Critical Protocols**: Proper sample collection, storage, and handling protocols are essential for optimal performance. Controlled conditions significantly improve measurement agreement (2.4% improvement in R^2: 0.988 vs 0.964).
4. **Equipment Considerations**: Device and test strip batch calibration are critical for accuracy. Proportional relationship indicates reliable, correctable performance.

9.2 Practical Implementation Insights

5. **User Adoption Patterns**: Grower acceptance varies by use case - precision valued for nutrient budgeting, but speed considerations favour visual estimation for quick assessments.
6. **Economic Advantage**: 80-90% cost savings make the method economically attractive even with quality assurance laboratory verification.
7. **Training Requirements**: Successful implementation requires proper training in both sampling techniques and device operation, achievable through structured workshop approaches.

9.3 Scope and Limitations

8. **Concentration Range Validation**: Current validation robust for 2-30 ppm NO_3-N found in the vegetable production systems assessed but requires extended testing at higher concentrations for broader application.
9. **System-Specific Application**: Method particularly suited to vegetable production systems with associated soil management practices, but requires validation for pastoral or other farming applications.

9.4 Spatial Variability Implications

10. **Natural Background Variability**: The method's precision (±7% difference) is appropriate for agricultural decision-making given the substantial natural spatial variability in soil nutrients documented by New Zealand researchers. Research by Yule and Grafton demonstrates that spatial variability in soil nutrients commonly exceeds the method precision achieved by Nitrachek, supporting its practical utility for farm management.

10 Research Priorities

10.1 High Priority (0-12 months):

1. Extended concentration validation (30-150+ ppm) for intensive agricultural systems
2. Device-to-device consistency evaluation and standardisation
3. Improved sample handling protocols to minimise transit effects

10.2 Medium Priority (1-2 years):

4. Farming system-specific calibrations for pastoral and arable applications
5. Digital integration with farm management systems
6. Environmental compensation algorithms for field conditions

10.3 Long-term (2-5 years):

7. Multi-parameter testing capabilities
8. Automated data capture and GPS integration
9. Precision agriculture integration with variable-rate equipment

10.4 Quality Assurance Framework

11 Essential Standards:

1. Regular device calibration before use sessions
2. Test strip batch verification with each new lot
3. Sample handling protocols following industry guidelines
4. Periodic laboratory cross-checking (frequency based on concentration range and application)
5. Documentation of calibration and environmental conditions

12 Future Development Opportunities

12.1 Agricultural Sector Extension:

1. Pastoral system validation and calibration
2. Arable crop management applications
3. Organic farming system adaptations

12.2 Regulatory and Compliance:

4. Environmental monitoring applications
5. Water quality assessment integration

13 Acknowledgments

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15 Appendices

Appendix A: Detailed Calibration Procedures

A.1 Nitrachek 404 Device Calibration

Daily Calibration Protocol

1. Power on device - Allow 30-second warm-up period
2. Insert white calibration stick - Push fully into measurement slot
3. Close hatch - Device should read "CAL"
4. Remove white stick and insert grey calibration stick
5. Close hatch – After one minute the device should read within manufacturer's specified range (typically 122-142 units)
6. Record calibration values in logbook with date, time, and operator initials

Troubleshooting Calibration Issues

- If grey stick reading outside range: Clean measurement chamber and repeat. If still outside range, contact manufacturer for service
- If readings drift during day: Recalibrate and check environmental conditions

A.2 MQuant Test Strip Batch Calibration

Standard Solution Preparation

- Prepare 100 ppm NO_3 standard solution using analytical grade KNO_3
- Solution stability: Use within 7 days when stored at 4°C
- Verify concentration monthly using laboratory analysis

Batch Testing Protocol

1. Test 5 strips from new batch with 100 ppm standard solution
2. Record individual readings and calculate average
3. Calculate correction factor using Equation 15-1:

Equation 15-1 Test-strip Batch Correction Factor Calculation

$$Correction\ factor\ =\ \frac{100}{average\ value}$$

4. Determine Lot Setting according to Table 15-1:

Table 15-1 Lot Number Assignment Based on Correction Factor

Correction Factor Range	Lot Number	Expected Accuracy
<0.83	1	±15%
0.83-0.87	2	±12%
0.88-0.92	3	±10%
0.93-0.97	4	±8%
0.98-1.02	5	±5%
1.03-1.07	6	±8%
1.08-1.12	7	±10%
1.13-1.17	8	±12%
>1.18	9	±15%

A.3 Quality Control

- Reject batches with correction factors <0.70 or >1.30
- Document all batch calibrations with lot numbers and dates
- Test new batch against old batch before switching

A.4 Sample Storage and Handling Protocols

Field Sampling Requirements

- Use clean, dry sampling tools for each location
- Collect samples in waterproof, labelled containers
- Record GPS coordinates and sampling depth
- Photograph sampling location for reference

Storage Protocol

- Maintain temperature <4°C during transport
- Use insulated containers with ice packs for >2 hour transport
- Avoid direct contact between samples and ice
- Process samples within 24 hours of collection

Laboratory Processing

- Allow samples to equilibrate to room temperature (20±2°C)
- Sieve through 5mm mesh before sub-sampling
- Use consistent soil:solution ratios (1:3 by volume)
- Maintain extraction time at 4-5 minutes

Appendix B: Soil moisture correction using FAR Tool

The FAR Soil Correction Value is determined from Table 15-2 based on selected values for soil texture and moisture.

Table 15-2 FAR soil correction table.

Texture	Dry	Moist	Wet
Clay	1.8	1.5	1.3
Clay loam	1.7	1.4	1.3
Loam	2.0	1.5	1.3
Loamy sand	1.8	1.5	1.4
Sand	1.8	1.5	1.4
Sandy clay	1.8	1.4	1.3
Sany clay loam	1.9	1.6	1.4
Sandy loam	2.1	1.8	1.5
Silt	1.9	1.4	1.3
Silt loam	1.7	1.4	1.3
Silty clay	1.9	1.6	1.4
Silty clay loam	1.9	1.5	1.4

The values in Table 15-2 are based on typical gravimetric soil moisture levels of standard soil types at approximate soil moisture tensions: Saturation, Field Capacity, and (Permanent) Wilting Point (Figure 15-1). There is considerable variation between specific soils that is not captured by these values.

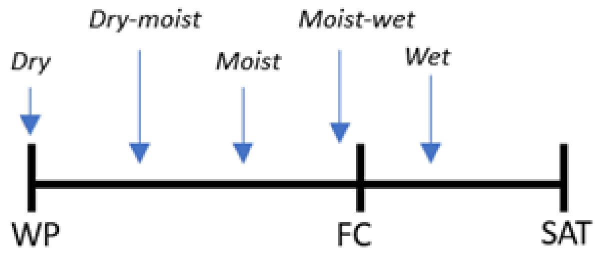

Figure 15-1 FAR soil moisture based on volumetric water content at wilting point (WP), field capacity (FC), and field saturation (SAT) for the soil the nitrate testing is carried out on.

It is important to note that the FAR Soil Correction table (Table 15-2) does not include a value for peat soils. The soil correction used for the two Ludlow samples elected the sand option, assuming equivalent porosity.

Appendix C: Statistical Analysis Methods

C.1 Analytical Approach

Statistical analysis was conducted with assistance from Claude AI (Anthropic) to ensure rigorous evaluation of method correlations, regression modelling, and bias assessment across different sample sets and conditions.

C.2 Data Processing Methods

A matrix of 40 soil samples with complete measurements were analysed using mass of nitrate nitrogen per hectare (kg NO_3-N ha^{-1}) data calculated using the FAR tool, Norris Factor, and Hill Labs NO_3-N methods.

Quality Classification

- High Quality (Sets 2+3): 24 samples with reliable Hills laboratory data from controlled MicroFarm conditions
- Moderate Quality (Set 1): 16 samples with compromised Hills data due to delivery problems from regional farms

C.3 Statistical Models Evaluated

Through-Origin Regression (Selected)

- Theoretical basis: Both methods measure the same physical quantity (soil nitrate)
- Mathematical assumption: Zero nitrate should yield zero reading on both instruments
- Statistical validation: Intercept term tested and found not significantly different from zero.

Free Intercept Model (Rejected)

- Tested for comparison but intercept lacked statistical significance
- More complex equation without theoretical justification
- See Table 1 for detailed comparison

Simple Ratio Method (Rejected)

- Overly simplistic approach ignoring measurement scatter
- No consideration of statistical uncertainty

C.4 Calibration Strategy

Primary calibration developed using high-quality data (Sets 2+3) with the Norris method as field standard calibrated against Hills laboratory reference. This eliminates sample handling confounding effects and establishes true method relationship.

Model Selection Criteria

1. Statistical fit (R^2 maximization)
2. Theoretical soundness (physical validity)
3. Practical implementation (equation simplicity)
4. Quality of underlying data (controlled vs. compromised samples)

For complete statistical results, see ***Error! Reference source not found.*** *in main text.*

Appendix D: Grower Feedback Summary

D.1 Regional Workshop Participation

Workshops were conducted across all four target regions (Hawke's Bay, Manawatu, Pukekohe, and Gisborne) with participation from both growers and agronomists. The workshops demonstrated and supported valid paddock sampling techniques and Nitrachek device operation, ensuring knowledge transfer within each region.

D.2 Grower Feedback on Device Adoption

Positive Feedback

- Growers and agronomists who participated in workshops indicated they would use the skills learned
- Some growers indicated they would use the Nitrachek in spring as part of their pre-planting soil testing
- One grower compared an alternative nitrate measuring device they were already using with the Nitrachek device and found both were giving similar results
- When they first purchased their device, they had compared results with Hill Labs testing and found general agreement, giving them confidence to use on-farm testing

Mixed and Negative Feedback

- Mixed feedback when it came to using the Nitrachek device itself
- Some growers found it too time-consuming, as the Nitrachek takes over one minute per test Reading strips by eye, they could do four or five tests in that time
- A few growers found the device operation satisfactory for their needs

D.3 Use Case Preferences

Preference Factors

Overall adoption seemed to depend on both personal preference for precise numbers and the purpose for which the Nitrate Quick Test was being used.

Device Precision vs. Speed Trade-offs

- Estimating colour was considered adequate to assure growers there was or was not sufficient nitrate available
- The device was more precise if a number was to be entered in a nutrient budget tool compared to visual estimation speed
- The Nitrachek device produces precise readings of nitrate concentration for users who prioritise accuracy over speed.

D.4 Implementation considerations

The workshops successfully engaged growers and agronomists across all regions, with participants able to learn sampling, sample processing, and Nitrachek device operation. The mixed feedback highlights the importance of matching the testing method to the specific use case and user preferences.

Appendix E: Calibration factor selection process

Why 1.076 was selected

The calibration factor 1.076 was determined through rigorous statistical analysis of 24 high-quality samples where both Nitrachek and Hills laboratory measurements were reliable. This factor represents the best mathematical relationship between the two methods.

Alternative approaches considered

- **Simple average ratio:** Would give 1.061, but ignores data scatter
- **Free intercept model:** Would give 1.115 × Norris - 0.92, but intercept not statistically meaningful
- **Through-origin model (chosen):** Hills = 1.076 × Norris, theoretically sound and statistically optimal

Why through-origin is best

- Both methods measure the same thing (soil nitrate), so zero soil nitrate should give zero reading on both
- Statistical test confirmed the intercept term was not significantly different from zero
- Simpler equation is more practical for field use
- Better behaviour at low nitrate concentrations

Appendix F: Statistical measures explained for practitioners

Understanding Correlation (r)

What it measures

How consistently two methods track together

- **Range:** -1 to +1, where +1 = perfect positive relationship
- Interpretation:
- r > 0.9 = Excellent relationship
- r 0.7-0.9 = Good relationship
- r < 0.7 = Poor relationship
- **Practical meaning:** High correlation means when one method reads high, the other also reads high

Understanding R-squared (R^2)

What it measures: Percentage of variation explained by the calibration

- **Range:** 0 to 1 (often expressed as percentage)
- **Interpretation:** Higher values mean the calibration equation predicts results more accurately
- **Practical meaning:** Shows how much of the difference between methods can be corrected by calibration

Understanding Error Metrics

Root Mean Square Error (RMSE):

- **Units:** Same as your measurements (kg/ha)
- **Meaning:** Typical size of prediction errors
- **Use:** About 68% of predictions fall within ±1 RMSE of true value

Mean Absolute Error (MAE):

- **Calculation:** Average of all error sizes (ignoring positive/negative)
- **Meaning:** Typical accuracy you can expect in daily use
- **Use:** Easier to interpret than RMSE - represents everyday accuracy

95% Confidence Interval:

- **Calculation:** Approximately ±2 × RMSE
- **Meaning:** Range where 95% of measurements should fall
- **Use:** Quality control trigger - investigate measurements outside this range

Statistical Significance

Purpose: Determines if results are real or just random chance

- **p-value:** Probability that results occurred by chance alone
- **$p < 0.05$:** Generally considered "significant" (less than 5% chance of being random)
- **Application:** Used to validate that calibration improvements are genuine

Model Selection Logic

Through-Origin vs. Free Intercept:

- **Through-origin:** Forces line through zero point (0,0)
- **When appropriate:** Both methods measure same thing, so zero input should give zero output
- **Advantage:** Simpler equation, better behaviour at low concentrations
- **Test:** Check if intercept is significantly different from zero

Specific values for this study are provided in Table 3-1 of the main report.

Appendix G: Quality Assurance Explained in Detail

G.1 Understanding Accuracy Expectations

Reference: All accuracy figures refer to values calculated in Table 1 of main report.

Typical Field Performance

- **Expected accuracy:** Refer to MAE value in
- **Meaning:** Half your measurements will be more accurate than this, half less accurate
- **Daily use:** This represents realistic expectations for routine field testing

Quality Control Range

- **Control limits:** Refer to 95% confidence interval in Understanding Error Metrics
- **Meaning:** Only 1 in 20 measurements should exceed this range
- **Action trigger:** Investigate any results outside this range

G.2 Optimal Operating Conditions

Best Performance Conditions (See Table 3-4 for soil-specific validation)

- **Soil type:** Silt loam soils (most validated)
- **Concentration range:** 2-30 ppm NO_3-N (95% of study samples)
- **Sample handling:** Controlled temperature, proper storage
- **Equipment status:** Recently calibrated, good test strip batch

Reduced Accuracy Expected

- **Different soil types:** Limited validation data (see Table 3-4)
- **Extreme concentrations:** Outside validated range
- **Poor sample handling:** Temperature abuse, delayed processing
- **Equipment issues:** Calibration drift, old test strips

G.3 Investigation Triggers

When to Investigate Results

1. Single measurement outside control range

- **Threshold:** See Table 3-3 Quality Control Metrics for specific values
- **Action:** Recheck moisture measurement, verify equipment calibration, consider duplicate sample

2. Systematic bias pattern

- **Pattern:** Multiple consecutive results consistently high or low compared to expectations
- **Action:** Compare with laboratory analysis, check calibration drift

3. Equipment performance issues

- **Signs:** Inconsistent duplicate readings, display instability, obvious equipment damage
- **Action:** Recalibrate device, replace test strips, service equipment

4. Unusual field conditions

- **Examples:** Waterlogged soil, extreme drought, recent lime application, high organic matter
- **Action:** Extra care with protocols, consider laboratory backup

G.4 Maintenance Schedule

Daily Operations

- Device calibration before use
- Record environmental conditions
- Document any unusual observations

Per Test Strip Batch

- Batch calibration with standard solution
- Calculate and apply correction factor
- Document batch performance

Annual Verification

- Laboratory comparison (5-10 paired samples)
- Recalculate calibration if needed
- Equipment service check

Quality Documentation

- Maintain calibration logs
- Record investigation outcomes
- Track accuracy trends over time

G.5 Troubleshooting Guide

Problem: Results seem too high/low

- **Check:** Moisture measurement accuracy
- **Check:** Test strip batch calibration
- **Check:** Sample storage conditions
- **Action:** Re-measure with fresh sample if issues found

Problem: Inconsistent duplicate readings

- **Check:** Equipment calibration
- **Check:** Sample homogeneity
- **Check:** Test strip quality
- **Action:** Service equipment if problems persist

Problem: Poor correlation with laboratory

- **Check:** Sample handling protocols
- **Check:** Calibration currency
- **Check:** Concentration range validity
- **Action:** Recalibrate using fresh laboratory comparisons

For specific numerical thresholds and performance expectations, refer to Table 3-3 Quality Control Metrics – *Table 3-3 in the main report.*

16 Contact

Contact Information: For questions about implementation or technical guidance, contact LandWISE Inc. research team.

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Data Availability: Full dataset and analysis code available for research purposes upon request.

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